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# Occupational health hazards of fabric bag filter workers' exposure to coal fly ash

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**The objective of the study was to assess employees' exposure to coal fly ash dust during the replacement of fabric bag filters in bag houses at a power station. Personal and environmental sampling were conducted on a random sample of workers. Samples that were in excess of occupational exposure limits (OEL) for respirable fly ash were analysed for toxic metals. Physical observations and a questionnaire were used to determine awareness of employees on the health effects of coal fly ash dust exposure. The results from personal dust sampling ranged from 20.7 to 477.2 mg/m$^3$ with an average of 101.2 mg/m$^3$. All the results were above the 5.0 mg/m$^3$ legal threshhold specified in the applicable South African legislation. Static dust sampling results ranged from 2.2 to 28.7 mg/m$^3$ with an average of 13.5 mg/m$^3$. Only 8% of the static dust samples were below the OEL for respirable dust (≥ 5mg/m$^3$). Results that were obtained from toxic metal analysis were far below the OEL. Good awareness by employees regarding the health effects of exposure to coal fly ash and awareness of respiratory zones was also reflected. Control measures are recommended to reduce the exposure risk to fly ash.**

**Key words:** Workers exposure, coal fly ash, occupational hazards, fabric bag filters.

## INTRODUCTION

At a coal-fired electricity generating plant, coal is the main raw material for production and it is expected that employees will be exposed to coal dust (with a probability of developing silicosis because of the prevalence of crystalline silica in coal) at various stages of production. This kind of low grade coal produces a high yield of ash after combustion in the boilers. It is because of this high yield that is, there is a probability of high concentration of toxic metals in the ash that is generated, considering that 15% of ash is produced from combustion of coal (Boswell, 1987). Dermatitis, bronchitis, eye injuries and lung diseases can result from exposure to hazardous dust (Agius, 2001). Fly ash as a waste by-product of the electricity generation process consists mainly of fine particles. The particle sizes of fly ash dust are according to Meij and te Winkel (2000) distributed on the basis of internationally accepted differentiation between inhalable and respirable fractions in these proportions: 50 μm (55%), 10 μm (20%), 4 μm (5%) and 2.5 μm (1%).

Studies conducted by UNIPEDE (1995) revealed that bulk fly ash has an alpha-quartz content of between 0.1 and 11% in the respirable fraction. The potential for alpha quartz exposure exists if there is high quartz content in the coal feed stock. However, its toxicity is significantly reduced by the high combustion temperature (approximately 1800°C) in modern power stations. This results in the quartz being converted from crystalline to a non-hazardous vitrified form. It is because of the formation of a glassy material that fly ash was considered as being relatively inert and innocuous after combustion Elemental analysis of the fly ash shows that the main components are silicon, aluminium, and calcium (EURELECTRIC, 2000).

Due to its composition and genesis, coal fly ash exhibits pozzolanic properties; it reacts with dissolved calcium hydroxide and water at normal temperature to

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form strength developing minerals in a similar manner to cement (EURELECTRIC, 2000). The composition of fly ash is dependent upon the mineral matter present within the coal that is fired in the furnace and the effectiveness of combustion that has taken place (Sear et al., 2004). Cook (1983) specifies that glassy particles in fly ash are probably the most important pozzolanic constituent. The reactions of the glassy particles with lime released during hydration of cement produce secondary cementatious compounds. Cook (1983) further states that there is a general agreement that the finer the fly ash, the higher the pozzolanic activity. In general, the finer ashes react quicker to produce slightly higher early strengths and slightly faster set times. The glass in fly ash is the most reactive component in cementation and an increase in the mineral content would reduce the pozzolanic efficiency of the ash (Lesch, 1987). According to studies undertaken by EURELECTRIC (2000) typical fly ash also contains additional metal oxides such as $TiO_2$, MgO, $K_2O$ and $P_2O_5$ at 1 to 3% and $Pb_2O_5$ at 0.3 to 3%.

Employees at coal-fired power generating plants are generally not exposed to high concentrations of fly ash dust because the ash is enclosed within the production system. However, there are tasks or activities such as maintenance on electrostatic precipitators, hoppers, bag houses and conveyers whereby employees are likely to be exposed to high concentrations of this dust (ESKOM, 1996).

## Aim and objectives

The aim of the study was to determine the extent of exposure of workers maintaining fabric filter plants to fly ash and to determine their level of knowledge and awareness on hazards and risks accociated with their excopure to fly ash. The objectives were to:

1. Assess employees' exposure (personal and environmental exposure) to fly ash dust.
2. Compare the sampling results to the legal occupational exposure limits (OELs) for dust.
3. Determine the occupational hazard awareness levels of exposed workers and
4. Recommend measures to control and/or reduce the risk of exposure to fly ash dust.

## MATERIALS AND METHODS

The study employed a mixed method approach: 1) Laboratory based analyses, 2) Observations, and 3) Questionnaire for workers. Such an approach allowed for a multi-dimensional analysis of occupational hazards related to exposure bag filters workers to coal fly ash by fabric.

### Description of study site

The Duvha Power Station is situated 15 km east of Witbank in the Mpumalanga province of the Republic of South Africa. It is the only Eskom coal-fired electricity generating station that utilises both bag houses and electrostatic precipitators as means of controlling the particulate emissions into the atmosphere. The rest of Eskom's coal-fired electricity generating stations utilises electrostatic precipitators only. Three of the generating units at Duvha Power Station utilise Optipulse pulse-jet fabric filter in the bag houses. In 1993 Duvha Power Station became the first power station in the world to be retrofitted with pulse jet fabric filter plant on three of its six units. The rest of the units function on electrostatic precipitators. These plants contribute largely to the reduction of air pollution by removing 99.99% of the fly ash otherwise released into the air through the station's chimneys. For each corresponding unit there are 4 compartments or cells in a baghouse. There are about 6 724 filter bags in a compartment, each of which is eight meters long, giving a total of 26 896 bags per unit (Duvha Power Station Technical Information, 1996). The bag house as means of controlling emissions is one of the approved, effective and efficient methods in the control of particulate air pollutants. This method, just like any production process requires maintenance whereby the fabric filter bags are replaced with new ones.

The process of replacing bag filters in the bag houses is undertaken alternately in the units. The frequency of the bag replacement is dependent on the performance of the stack emissions. The more dust that is emitted from the stacks, which is indicative of poor performance of the bags, the more frequent this operation will take place. This operation for bag replacement if undertaken is frequently done biannually and this process is carried out manually (Figure 1). Prior to the fabric filter bags' replacement project, the unit or plant is shut down or taken off production cycle for bag house maintenance. This action is undertaken in order to allow for the cooling down of the area and to reduce the risk of exposure to the hazards of flue gases as well as heat. There are 15 employees during a shift that are involved in the task of replacement of bag filters inside a bag house. During the replacement of the fabric filter bags these employees are in direct contact with fly ash dust. The fly ash dust is known to consist mainly of particles that are below the 10 µm size range. This dust fraction is therefore considered to be respirable and will reach the alveoli once it is inhaled, thus could increase the risk of causing pulmonary diseases such as silicosis if it contains crystalline silica (Health and Safety Executive, 1986). This study was initiated because of lack of sufficient scientific knowledge and evidence by employees and employers alike at the power station on the toxicity and health hazards associated with exposure to fly ash dust when replacing bags at baghouse units.

### Sampling and analysis

Personal (64) and static (26) samples for respirable fly ash dust were collected between routine maintenance shutdowns of the fabric bag filter plant. The procedure that was followed for the personal and static sampling of respirable fly ash dust in the bag house was a combination of methods health and safety executive (HSE) MDHS 51 (for flow rate calibration of personal samplers), NIOSH 0600 and NIOSH 7300 (for trace metals). The NIOSH 0600 method is for the determination of respirable dust and is applicable for the sampling of any non-volitile respirable dust and is also recommmend for respirable coal dust sampling. The method requires that a polyvinyl chloride (PVC) filter be used for the collection of dust particles. The filters are to be equilibrated and weighed before and after sampling. The method requires in addition that a cyclone be used in collecting the respirable dust fraction. An air flow sampling rate of 1.7 and 2.2 ℓ/min needs to be maintained pending on the type of cyclone that is used. Thirty seven (37) mm diameter, 0,8 µ pore diameter mixed cellulose ester (MCE) filters and support pads were used for the collection of samples. The


**Figure 1.** Fabric filter bags removed that are ready for disposal.

MCE filters were chosen for their suitability for laboratory analysis of metals by inductively coupled plasma spectoscopy. Personal and static sampling was conducted for the entire shift (8 h) or at a minimum of 80% of the shift-time when bag filters were replaced in the bag house. Where only 80% of the shift time was applicable the unsampled (20%) of exposure concentration remained constant. Throughout the sampling period it was confirmed that the sampling pumps were operational for the entire sampling periods. Where problems existed with the running of pumps, sampling was terminated and then resumed with a new set of sampling equipment (normally during a next work shift). Flow rate calibration was excersised according to MDHS 51. Sampling for quartz were not conducted as the high temperature achieved during the combustion of coal changes the chemical composition and quartz is not formed. Polycyclic aromatic hydrocarbon (PAH) and silica were also not sampled as the study was limited to the workers' fly ash exposure from the combustion process.

The respirable fly ash dust samples with concentrations that were ranging from 40 to 450 $mg/m^3$ were selected at random, transported and submitted to the laboratory for the determination of identified toxic trace metals. Twenty nine (26) samples were analysed at a laboratory that is accredited by the South African National Accreditation Services (SANAS) for analysis of toxic trace metals. The laboratory analysed the respirable dust fractions for concentrations of toxic trace metals using the inductively coupled plasma (ICP) analytical technique. An aqueous medium was only used where the levels of toxic metals were high on the samples that were dissolved in acid medium.

**Observations and worker interviews**

Physical observations were conducted and photographs taken before and during the process of replacement of bag filters in bag houses. The purpose of obervations was to establish worker knowledge and practice levels, attitudes and working conditions. In addition, a questionnaire was administered to workers during the same time as sampling took place.

Questionnaires were used to evaluate the level of occupational hygiene knowledge and training of exposed employees regarding the hazards of fly ash dust in order to recommend the development of training guidelines for the control of personal exposure whilst replacing the fabric filter bags in the bag houses. Questionnaires were developed to include questions on training competencies of employees as well as their awareness of the health hazards of fly ash dust. Questionnaires were administered to a representative group of employees that were selected at random to establish the profiles based on the above aims and objectives. It was decided to use a sample of 31 employees from a population of 45 workers engaged in this operation. This number was statistically considered as being representative for the population that is engaged in the replacement of fabric bag filters in the bag houses.

Prior to administering these questionnaires, workers were engaged in a meeting and briefed about the purpose of the study. In this meeting it was identified that some of the workers were incompetent in speaking and writing english and were unable to complete the questionnaires on their own. To ensure consistancy in the data, such employees were assisted by the researcher and the

**Table 1.** The statistical analysis of fly ash dust concentration results.

| Statistical information | Static samples | Personal samples |
|---|---|---|
| Sample size | 26 | 64 |
| Range (mg/m$^3$) | 2.2 - 28.7 | 20.7 - 477.2 |
| Minimum (mg/m$^3$) | 2.2 | 20.7 |
| Maximum (mg/m$^3$) | 28.7 | 477.2 |
| Mean (mg/m$^3$) | 13.54 | 101.2 |
| Standard deviation | 7.65 | 87.8 |

safety representative of the workers together, in interpreting and completing the questionnaire. To the rest of employees the questionnaires were explained to them and issued for completion. These employees were allowed two days to complete questionnaires in order to allow sufficient time for response. Data collected on questionnaires was analysed using the Epi info statistical software programme (EPI INFO, 2004). The project was approved by the ethical committee of the Institution under which auspices the research was carried out. Interviews were held with an aim to further establish if cases of fly ash dust over exposure were reported to both the medical centre and the safety departments and to determine what precautionary measures are taken in order to alleviate the risk of overexposure to fly ash dust.

Physical observations were undertaken for supporting information that was collected from the questionnaires. A check sheet was used to include all items that were of interest to observe during the replacement of bag filters in bag houses. A digital camera was made available to assist in capturing scenes in the bag houses whilst bag filters were being replaced.

## RESULTS

### Fly ash dust samples for personal monitoring

The results for personal dust sampling revealed that all the results are at and above the occupational exposure limit for respirable fly ash dust (Table 1). The exposure duration of the individual workers sampled as well as for the static samples was representative of an eight hour shift. These results ranged from 20.7 to 477.2 mg/m$^3$ with an average of 101.2 mg/m$^3$. All the results from the personal samples were above the 5.0 mg/m$^3$ legal threshhold specified in the applicable legislation (SA, 1995).

### Fly ash dust samples for static monitoring

The results for static dust sampling (Table 1) revealed that not all the results were below the occupational exposure limit for respirable dust. The results ranged from 2.2 to 28.7 mg/m$^3$ with an average of 13.5 mg/m$^3$.

The results for static samples were generally lower than those obtained for the personal samples. The results were in most cases above the occupational exposure limit but with a less magnitude as compared to all the personal samples as shown in Table 1. The dust load of static samples was significantly lower as compared to the personal samples. This difference can be attributed to the fact that for the personal samples the collection media were located nearer to the point of action during sampling as compared to the static samples that represented a work area. The collection media for static samples were some distance from the point of action because of a lack of access sampling points in the bag house.

Personal samples were representative of all areas where employees were working while replacing the bags. This ranged from three to four workstations where the bag filters were handled. The static samples were located in one area and were not moved as employees were migrating from one workstation to the next. It was observed that while the employees moved from one area to the next, the dust load in an area with less activity was low, and this would therefore affect dust load at a static sample's point as action was minimised in a work environment. For personal samples in all areas, workers generated dust as they were working with the fabric filter bags and therefore the collection media would pick up a load of dust no matter how small the quantity in each area, when an activity is undertaken. The sampling range varied from 20.7 to 448.3 mg/m$^3$. A standard deviation of 87.8 is not unusual due to the fact that the sampling was not static and workers that carried the sampler moving around were differently exposed and only representative of the specific individual worker.

### Toxic metals concentration

For the toxic trace metals most of the results (Table 2 ) that were obtained were far below the OEL for the respective metals. This was in support of a previous assumption that although fly ash contains trace elements that are toxic, these are present in concentrations that are biologically insignificant (UNIPEDE, 1995). Their concentrations were indeed at trace levels and even at very high atmospheric fly ash concentrations the exposure limits of the respective metals were not exceeded. This study has scientifically confirmed this assumption. The only exception was the lead concentration where the results was in some samples approaching the OEL for this metal. The results of this

**Table 2.** Statistical analysis for toxic trace metals.

| Metal | Average mg/m$^3$ | Minimum mg/m$^3$ | Maximum mg/m$^3$ | Range mg/m$^3$ | OELs (mg/m$^3$) |
|---|---|---|---|---|---|
| Ba | 0.04 | 0.021 | 0.066 | 0.021 - 0.066 | 0.5 |
| Ni | 0.02 | <0.018 | 0.03 | <0.018 - 0.03 | * |
| Zn | 0.024 | 0.0134 | 0.055 | 0.0134 - 0.055 | 5 |
| Hg | <0.063 | <0.007 | <0.069 | <0.007- <0.069 | 0.05 |
| Cr | 0.013 | 0.001 | 0.021 | 0.001 - 0.021 | 0.5 |
| Cu | 0.0308 | 0.001 | 0.08 | 0.001 - 0.08 | 0.2 |
| V | <0.0609 | <0.07 | <0.069 | <0.07 - <0.069 | 0.05 |
| Mn | 0.007 | 0.001 | 0.029 | 0.001 - 0.029 | 5 |
| As | <0.065 | <0.063 | <0.069 | <0.063 - <0.069 | 0.1 |
| Pb | 0.0499 | <0.032 | 0.139 | <0.032 - 0.139 | 0.15 |

* Not available.

study could therefore not give conclusive information regarding the levels of toxic trace metals in the respirable fly ash dust. Even if the cumulative effect of the toxic chemicals are taken into consideration, no overexposure of workers is expected.

### Interview results with safety and health management

The interviews with the Safety and Health Department at the Power Station have revealed that there were no cases or incidents reported of overexposure to fly ash dust at the power station for the past 5 years. It was because of this information that one could not establish exposure trends because of a lack of information. There is no dedicated awareness training regarding the hazards of exposure to fly ash dust. The training that is available is generic and is only given during induction for new and contract workers. There is therefore insufficient awareness and training on the hazards of fly ash dust.

### The questionnaires results

The questionnaire results revealed that of all employees that participated in the study, 96.7% agreed that fly ash dust is dangerous and can cause harm to them. 90% indicated that the ash affects them. 45.2% confirmed that they felt uneasy after being exposed to excessive concentration of fly ash, whilst 48.4% said that they never felt uneasy after being exposed to fly ash dust.

Of the employees involved in the replacement of bag filters in the bag house, Figure 2 indicates that 41.9% have been involved in this job for at least 2 years and 32.3% for at least 3 years of their period of employment and have confirmed that they are not working in this area on a daily basis.

Of all the employees that were interviewed, all answered positively that they were given information about the danger of over exposure to fly ash dust. All of the participants confirmed that the wearing of respiratory protection devices are meant for both employees and management while working in a high-risk area. Employees were able to identify a respirator zone because 87.1% correctly indicated how to describe such an area, while all of them knew how to identify it.

From the sample of employees that participated in the study, all confirmed that they had received training in the wearing of respirators. 61.3% of them confirmed the limitations of the respiratory protective devices that they were using (Figure 3), whilst 19.3% was unsure of the limitations of these devices. 90.4% think that the respiratory protection devices provide sufficient protection. 74.2% confirmed that training on the wearing of respiratory protection is given frequently; daily before starting with work. 68% of employees confirmed the wearing of respiratory protection for all the period that they spend working in the bag house during the replacement of bag filters.

### Physical observations while replacing bag filters

When observing employees working in the bag house, it was difficult to establish if a formalised or written safe work procedure was followed. There was no recognisable pattern of how the work is undertaken.

Only one type of a respirator was used during the bag replacement operation. It was therefore not required to compile a list of the respirators that are used at the power station. The employees were using these respiratory protective devices for the duration of operations while working in the bag house during replacing the fabric filter bags. There were however, some respirators that were partly not in good condition. There were those that had soiled cartridges which could ultimately render the device ineffective and insufficient for the intended task. Although these respiratory protective devices were kept in a central

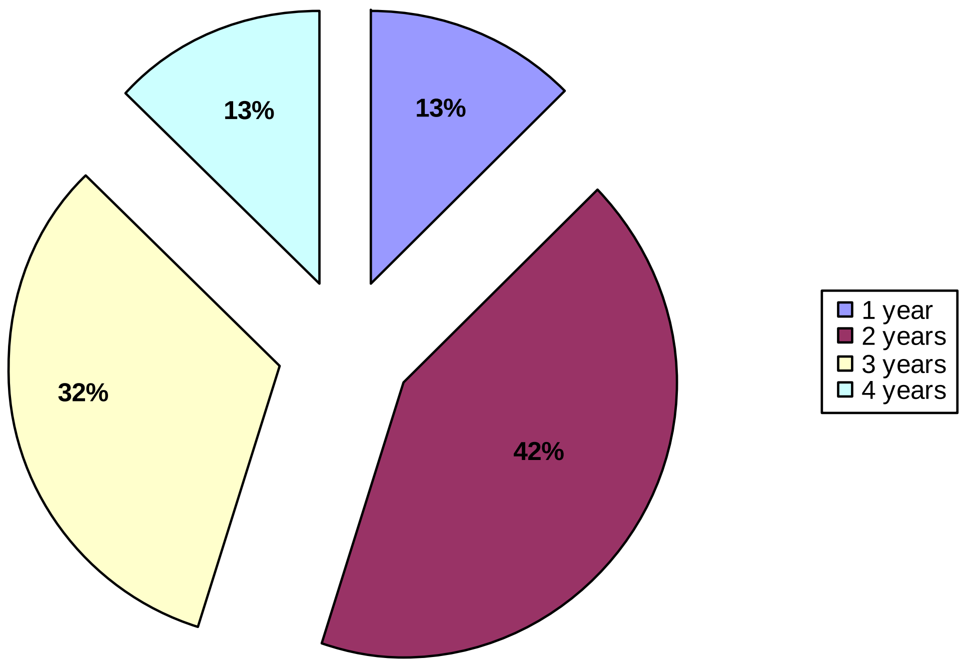


**Figure 2.** Years of experience working with fly ash.

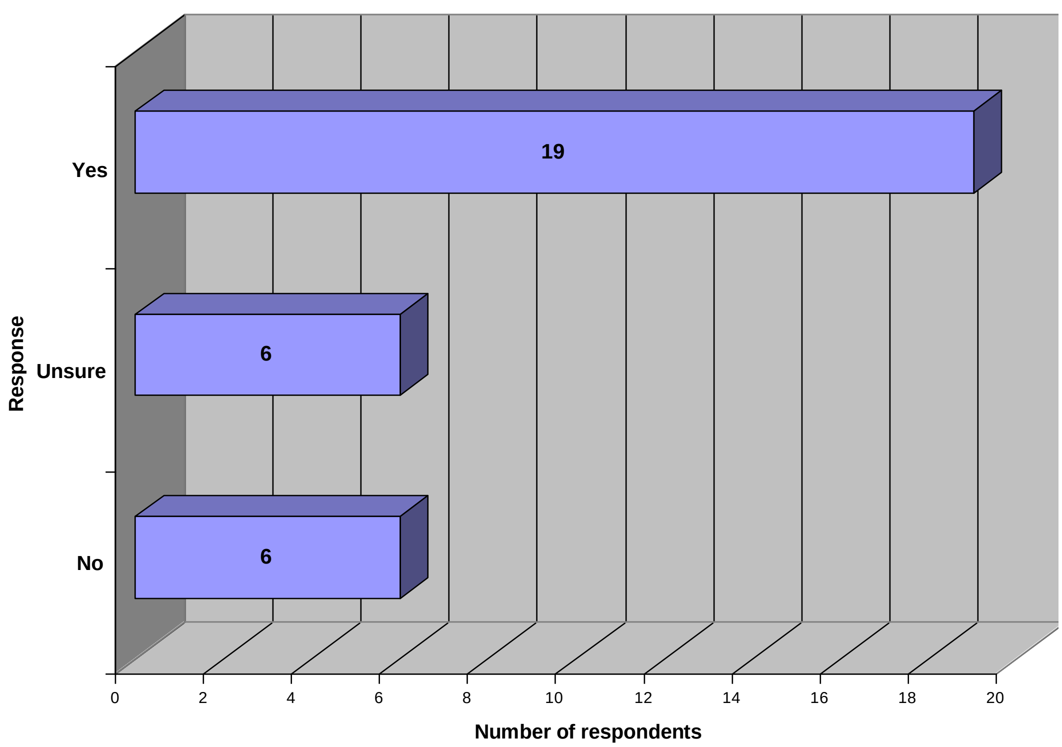


**Figure 3.** Knowledge on limitations of respirators.

place before and after use, the condition under which they are stored appeared to be inappropriate.

There was a concern regarding personal hygiene because employees were seen leaving/breaking for lunch while fully covered in a heavy load of fly ash dust on their clothing and faces. Attempts were not made for decontamination or showering prior to taking lunch. This action would cause employees to be exposed to fly ash dust through ingestion while on lunch. In addition, this also exposes other employees that are by the nature of their job not working in a dusty area/respirator zone. This practice is prohibited by the Regulations of Hazardous Chemicals Substances (South Africa, 1995).

## CONCLUSIONS AND RECOMMENDATIONS

A number of conclusions can be drwan from this study: First, that employees are exposed to high levels of fly ash dust during the replacement of fabric filter bags and that the results for toxic trace metals in respirable fly ash dust were inconclusive as far as over exposure of workers. The hypothesis that employees that are responsible for the replacement of bag filters in the bag houses are exposed to high fly ash dust levels that pose an occupational health risk was partially proven to be true mainly because of the inconclusive results of toxic trace metals that indicated that workers are not over exposed. Cumulative or possible combined effects were verified and results indicated that due to very low concentrations of the toxic metals, overexposure is not evident (Canadian IRSST, 2010).

Second, that training of employees should specifically address fly ash dust exposure because there were no records for such training and that the respiratory programme needs to be reviewed and enforced. Although awareness training is given, there are some deficiencies (for example, ineffective and insufficient respirators, personal hygiene, and decontamination before taking lunch) that need to be tightened up in improving the intervention. This would cause employees to be exposed to fly ash dust through ingestion whilst having lunch and also expose other employers that are by the nature of their not working in a dusty area/respirator zone. It could therefore be concluded that the hypothesis that training guidelines and safety knowledge are inadequate to address the training of workers responsible for replacing the bags in the bag houses, has been tested and proven to be true.

Third, there was no identifiable safe work procedure for the replacement of bag filters in the bag houses. Experience and age of workers could not be linked to causes of overexposure to fly ash dust while replacing fabric filter bags in the bag houses. No medical records of employees' exposure to fly ash dust were available and therefore it was not possible to determine trends of exposure. The records available are for general periodical medicals.

The study, found out that in most instances, personal protective equipment is provided only after all means of environmental controls have been considered. There are a number of instances where the use of respiratory protective equipment is likely to be the final, but adopted option for achieving acceptable long-term exposures to a substance (BOHS, 1996). This occurs where other control methods are not feasible to be implemented because of the limitations in the work environment as well as the material that is handled. It is therefore recommended that a respiratory protection programme be enhanced in order to reduce the risk of employees' exposed to fly ash dust. This is recommended because there are no feasible engineering control methods that could be instituted for controlling/reducing exposure. A respiratory programme such as NIOSH (1987) should be used as guideline for controlling/reducing the risk of exposure to fly ash dust.

A comprehensive safe work procedure should be developed and employees be trained on its application. This procedure will ensure that all employees work uniformly in the bag houses while replacing bag filters. Just as the Basel Convention EURELECTRIC (2000), whereby coal fly ash is tabulated in lists A and B for hazardous and non-hazardous wastes, this study revealed concentration levels of toxic trace metals below hazardous legal limits. Because of the cumulative nature of some of the chemicals such as mercury and lead, long term term exposure can lead to increased risk of over exposure of workers. These workers are exposed to flyash dust on a daily basis and they all had worked in those conditions for an average of 8 years. Most of them confirmed that they are exposed to high levels of flyash. Since this study only focused on respiratory dust from a compliance perspective, it is recommended that more research is required for the determination of toxic trace metals in fly ash be repeated by expanding the work in more than one power station and to include particle number concentration and size distributions including PM1.0. More emphasis should be placed at those power stations that utilise low grade coal. Future studies of this nature also needs focus on reliability analysis of results.

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